Study on Broadband Phased Array Antenna Using Log-Periodic Elements(対数周期素子を用いた広帯域フェーズドアレーアンテナに関する研究)

著者	金 大根
号	2605
発行年	2000
URL	http://hdl.handle.net/10097/7878

氏名	金　大根（キム　デグン）
授与学位	博士（工学）
学位授与年月日	平成１３年３月２６日
学位授与の根拠法規	学位規則第４条第１項
研究科，専攻の名称	東北大学大学院工学研究科（博士課程）電気・通信工学専攻
学位論文題目	Study on Broadband Phased Array Antenna Using Log-Periodic Elements
指導教官	東北大学教授 澤谷 邦男
論文審査委員	主査　東北大学教授　澤谷 邦男　東北大学教授　水野 皓司 東北大学教授　杉浦 行　東北大学助教授　陳 強

論 文 内 容 要 旨

Chapter 1. Introduction

It is often said that we live in the information age. In this information age, the importance of communication becomes higher and higher. In addition, the wireless or mobile communications, such as PDC and PHS, become amazingly widespread and it is expected that the share of wireless communications will exceed that of the wire communications sooner or later. Nowadays, the implementation of International Mobile Telecommunications-2000 (IMT-2000), so called the 3rd generation mobile communication, becomes one of the hot issues in the mobile communications field. If the IMT-2000 service starts, one can transmit or receive information such as voice, facsimile, data, still image, moving picture, etc. up to 2 Mbps, using 2 GHz bands, with the same quality as the fixed networks. For the sake of this service, various technologies such as the W-CDMA, the cdma2000, the CDMA I, the CDMA II, etc. have been proposed for the standard. What is more, the wireless Internet, wireless ad hoc networks, wireless LAN and Bluetooth also attract researchers' interest and are ready for service.

One of the fundamental devices for the implementation of those wireless technologies is a broadband antenna. There are various types of broadband antennas: the spiral antenna, the self-complementary antenna, the log-periodic antenna, the tapered slot antenna (TSA), etc. Furthermore, to provide the seamless and high quality of service (QoS) to as many users as possible, the smart antenna technology has attracted researcher's interest not only in the antennas and propagation area but also in the signal processing area. A phased array antenna, either a tracking-beam array or a switching-beam array, is basically employed for the smart antenna system. Therefore, a broadband phased array antenna is very important for providing the broadband services such as images and moving pictures through the radio in real time.

For the future application of the broadband and multi-band phased array antenna, the purposes of this study are to: (1) Perform the basic study on the planar broadband phased array antenna using LPDA antennas; and (2) Clarify the limitation of bandwidth of the broadband phased array antenna by evaluating scan performance.

Chapter 2. Array Factor of Broadband Array

In order to investigate the basic characteristics of broadband array antenna, the array factor of the 5×5 planar phased array of the isotropic point sources which have the unit strength is presented in this chapter.

Since the isotropic point sources are assumed, the mutual coupling between antenna elements is ignored. Three models of the array are examined to be compared with those of the planar phased array of the LPDA antennas in Chapter 4. Table 1 shows the array spacings of the models. The y-direction array spacing d_y is constant in all of the models, while x-direction array spacing d_x changes according to the models. Since our analysis models are triangular structures, the largest spacing between the neighboring elements is $\sqrt{d_x^2 + d_y^2}$, which is defined as the *effective array spacing* here. The directive gain of the array is defined and calculated. The sidelobe level (SLL) is defined as

$$\mathrm{SLL} = 10 \log_{10} G_{ls}/G_m \qquad [\mathrm{dB}], \tag{1}$$

where G_{ls} is the largest side lobe gain and G_m is the main lobe gain. The SLL of all of the models is also examined.

Under the criteria of $G_d \geq 14$ dBi and SLL $\leq$ -10 dB, the array bandwidth examples have been discussed. If the array bandwidth is defined as the bandwidth in which the main beam can be scanned to 30° in all the scan planes, only Model II satisfies the broad bandwidth of more than 2.0:1. If the main beam can be scanned to 20° in all the scan planes, Model II and Model III show the broadband characteristics.

Table 1: Analysis models.

Model I	Model II	Model III
$d_x = 50$ mm	$d_x = 72$ mm	$d_x = 125$ mm
$d_y = 125$ mm	$d_y = 125$ mm	$d_y = 125$ mm

Chapter 3. Log-Periodic Elements and Two Element LPDA Phased Array

As broadband antenna elements, the log-periodic dipole array (LPDA) and the log-periodic printed dipole array (LPPDA) have been presented. The LPDA antenna has 22 dipole elements and a 10:1 bandwidth, while the LPPDA antenna has 14 dipole elements and about 3:1 bandwidth. The method of moments (MoM) and the finite difference time domain (FDTD) method were used to numerically analyze the LPDA and the LPPDA antennas, respectively, taking advantage of their merits. From the comparison between the numerical and experimental results of the input impedance, the VSWR and the radiation pattern, the feasibility of the numerical method was verified.

The two element phased array of the LPDA antenna elements with a 10:1 bandwidth has been presented as a basic study for the broadband phased array antenna. The scan performance has been evaluated by the specific criteria such as the actual gain, the SLL and the scan angle deviation (SAD), where the SAD is the angle difference between the main lobe direction and the desired direction. Even though it is difficult to find the broad bandwidth which satisfies all the criteria, if some trade-off is allowable between the gain, the SLL and the SAD, a broad bandwidth is possible for the broadband phased array antenna.

Chapter 4. Multi-Element LPDA Phased Array

In this chapter, the 5×5 LPDA phased array antenna has been examined through the three different models. The LPDA antenna element has a 3.33:1 bandwidth (600–2000 MHz) as a single element. The mutual couplings and the array element patterns have been presented. The scan patterns have been presented in terms of the actual gain. The scan performance has been evaluated by the actual gain change, the SLL and the SAD.

As design examples for the specific application of the broadband phased array, the criteria of $G_W \geq 14$ dBi, SLL $\leq$ -10 dB and |SAD| $\leq 5°$ have been employed to find the feasible bandwidth. Table 2 summarized the results of the design examples. For the scan angle $\theta_0 = 30°$, there is no bandwidth to satisfy all the criteria along all the scan planes. However, a broad bandwidth can be obtained when the scan angle θ_0 is equal to or less than 20°.

In order to understand the mutual coupling effect between the LPDA antenna elements, the array factor bandwidth B_{AF} of Chapter 2 and the LPDA bandwidth B_{LPDA} of this chapter have been compared for all the analysis models. Although the LPDA phased array has narrower bandwidth than the theoretical AF phased array, the LPDA phased array can obtain a certain wide bandwidth when the scan angle θ_0 is equal to or less than 20°.

Table 2: Feasible bandwidth ($G_W \geq 14$ dBi, SLL $\leq$ -10 dB and $|\text{SAD}| \leq 5°$).

	Model I	Model II	Model III
$\theta_0 = 0°$	2.5:1 (800–2000 MHz)	2.86:1 (700–2000 MHz)	2.83:1 (600–1700 MHz)
$\theta_0 = 10°$	2.5:1 (800–2000 MHz)	2.86:1 (700–2000 MHz)	2.17:1 (600–1300 MHz)
$\theta_0 = 20°$	1.9:1 (1000–1900 MHz)	2.0:1 (800–1600 MHz)	1.17:1 (600–700 MHz)
$\theta_0 = 30°$	– (–)	– (–)	– (–)

Chapter 5. Conclusions

With the vision of the realization of the broadband phased array antenna for the near future application, the LPDA phased array antenna has been presented in this thesis. In order to understand the array characteristics, the three models of the 5×5 planar phased array of the isotropic point sources have been analyzed numerically by using the directive gain of the array factor and by investigating the scan patterns in terms of the SLL. As broadband antenna elements, the LPDA antenna and the LPPDA antenna have been presented. The two element phased array of the LPDA antenna elements with a 10:1 bandwidth has been presented as a basic study for the broadband phased array antenna to find the appropriate bandwidth of the single element for the broadband phased array. The 5×5 LPDA phased array antenna has been examined through the three different models, in which the LPDA antenna element has a 3.33:1 bandwidth (600–2000 MHz) as a single element. The mutual couplings and the array elements patterns have been presented. The scan patterns were presented in terms of the actual gain. The scan performance has also been evaluated by the actual gain change, the SLL and the SAD. Even though it is difficult to find the broad bandwidth which satisfies all the criteria, if some trade-off is allowable between the gain, the SLL and the SAD, a broad bandwidth is possible for the LPDA phased array antenna. Conclusively, it is worthwhile to note that the broadband phased array can be possible for the specific applications.

論文審査結果の要旨

近年，移動通信を始めとして電波の利用分野が拡大しており，複数の無線システムに共用できるアンテナが望まれている．また，移動通信におけるフェージング対策などの目的から，高速でビームを走査できるフェーズドアレーが必要になっており，広帯域フェーズドアレーアンテナの研究が重要になっている．著者は広帯域アンテナ素子として対数周期ダイポールアレー（LPDA）アンテナを取り上げ，これをアレー化したときの基本特性について検討を加え，周波数帯域幅の限界などを明らかにした．本論文はこれらの研究成果をまとめたもので，全編5章よりなる．

第1章は緒言である．

第2章では，等方性アンテナ素子を仮定してアレーファクタの検討を行った結果について述べている．アレー構成として5×5の3角配列を取り上げ，素子間距離を変えて指向性利得やサイドローブレベルの走査特性を求め，低周波領域では利得の低下によって，また高周波領域ではグレーティングローブの発生によってそれぞれアレーアンテナの周波数帯域の下限と上限が決定されることを定量的に明らかにしている．

第3章では，まずLPDA素子の解析について述べており，モーメント法を改良した方法を用いることにより高精度の解析が可能であることを示している．また，プリント化LPDAの特性についても言及している．さらに，2素子配列LPDAの素子間相互結合，動作利得，サイドローブレベル及びビーム走査誤差を評価し，2素子の場合には走査誤差が大きいために広帯域フェーズドアレーアンテナの実現が困難であるとの結論を得ている．これらは，LPDA素子を用いたアレーアンテナの設計指針を与えたもので，重要な知見である．

第4章では，LPDAを5×5の3角配列としたときの走査特性を求めた結果について述べている．また，第2章の結果と比較し，走査角度が20°以下程度と小さい場合にはアレーファクタを用いた検討が有効であり，比帯域1：1.8程度が得られるが，走査角を大きくするとアレーファクタを用いた検討では不十分であり，LPDAを配列した場合の方が狭帯域になることなどを明らかにしている．これらは，広帯域フェーズドアレーアンテナの帯域幅の限界を与えたもので，高く評価できる．

第5章は結言である．

以上要するに本論文は，LPDA素子を配列したフェーズドアレーアンテナの特性を高精度で解析し，走査角度に対する周波数帯域幅などを明らかにしたもので，アンテナ工学ならびに無線通信工学の発展に寄与するところが少なくない．

よって，本論文は博士（工学）の学位論文として合格と認める．